Medial Malleolar Fractures: A Biomechanical Study of Fixation Techniques

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abstract

Fracture fixation of the medial malleolus in rotationally unstable ankle fractures typically results in healing with current fixation methods. However, when failure occurs, pullout of the screws from tension, compression, and rotational forces is predictable. We sought to biomechanically test a relatively new technique of bicortical screw fixation for medial malleoli fractures. Also, the AO group recommends tension-band fixation of small avulsion type fractures of the medial malleolus that are unacceptable for screw fixation. A well-documented complication of this technique is prominent symptomatic implants and secondary surgery for implant removal. Replacing stainless steel 18-gauge wire with FiberWire suture could theoretically decrease symptomatic implants. Therefore, a second goal was to biomechanically compare these 2 tension-band constructs.

Using a tibial Sawbones model, 2 bicortical screws were compared with 2 unicortical cancellous screws on a servohydraulic test frame in offset axial, transverse, and tension loading. Second, tension-band fixation using stainless steel wire was compared with FiberWire under tensile loads. Bicortical screw fixation was statistically the stiffest construct under tension loading conditions compared to unicortical screw fixation and tension-band techniques with FiberWire or stainless steel wire. In fact, unicortical screw fixation had only 10% of the stiffness as demonstrated in the bicortical technique. In a direct comparison, tension-band fixation using stainless steel wire was statistically stiffer than the FiberWire construct.
For unstable ankle fractures that involve the medial malleolus, operative treatment is generally recommended. Multiple techniques, including bioabsorbable implants, have been used for fixation of the medial malleolus; however, the most common technique as recommended by the Association for the Study of Internal Fixation (AO-ASIF) group uses two 4-mm partially threaded cancellous lag screws placed perpendicular to the fracture line. Collinge et al showed that stainless steel cancellous screws had up to 24% less pullout force, significantly less torsional and bending strength than a 3.5-mm bicortical screw. There is little evidence reported in the literature on bicortical fixation of medial malleolar fractures.

The AO-ASIF group recommends tension-band wiring for small avulsion type fractures of the medial malleolus that are unacceptable for screw fixation as well as for osteoporotic bone. A well-documented complication of tension-band fixation of the medial malleolus is prominent symptomatic hardware, largely due to the subcutaneous nature of the medial malleolus, that often requires a second operation for hardware removal. Replacing stainless steel wire with FiberWire (Arthrex Inc, Naples, Florida) suture could theoretically decrease the incidence of symptomatic hardware and therefore decrease secondary procedures.

The purpose of this study was to first examine the biomechanical properties of fixation of medial malleolar fractures using bicortical screws compared to traditional unicortical partially threaded cancellous screws. Second, we aimed to compare the strength of a tension-band construct using FiberWire in a figure-of-eight fashion versus the AO technique using stainless steel wire. Finally, we compared stiffness across all fixation constructs under tensile loading.

**Materials and Methods**

For this study, we used a fourth-generation composite tibial Sawbones model (Pacific Research Laboratories Inc, Vashon, Washington). Recent studies have shown that fourth-generation models more closely replicate human bone with respect to tensile properties and average stiffness and strains compared to older generation Sawbones models. Studies also have shown a significantly decreased variability between specimens, providing more consistent results of biomechanical studies.

All specimens were prepared by a single surgeon and randomized into either the screw fixation groups (two groups of 30) or the tension-band wiring groups (two groups of 10). Prior to osteotomy, the specimens were predrilled with the corresponding drill bits or K-wires depending on the fixation group to decrease variability in the reduction quality between specimens. Slightly oblique osteotomies of the medial malleoli were created at the level of the tibial plafond as seen in Orthopaedic Trauma Association (OTA) type 44-B2.2 ankle fractures. The fractures were reduced with pointed reduction clamps, and fixation was conducted using 4 different techniques.

- **Construct 1:** two 4×40-mm partially threaded unicortical cancellous screws were placed perpendicular to the fracture line (Synthes, Paoli, Pennsylvania) (Figure 1A).
- **Construct 2:** two 3.5×75-mm fully threaded bicortical screws were placed perpendicular to the fracture (Synthes) (Figure 1B).
- **Construct 3:** two 2.0-mm K-wires were placed perpendicular to the fracture in a bicortical fashion with a figure-of-eight, 18-gauge stainless steel wire; the wire was simultaneously tightened in a double-loop configuration; and the wire then was anchored proximally through an anterior-to-posterior 1.8-mm drill hole, 2.5 cm proximal to the plafond (Figure 2A).
- **Construct 4:** two 2.0-mm K-wires (Synthes) in a bicortical fashion with a #5 FiberWire in a figure-of-eight fashion were tensioned to 25 lbs of force using a FiberWire tensioning device to decrease variability in the suture constructs (Arthrex), and a 4×20-mm fully threaded cancellous screw (Synthes) was placed 2.5 cm proximal to the plafond to anchor the proximal limb of the FiberWire (Figure 2B).

Radiographs of the tension-band wiring constructs are shown in Figure 3. The screw fixation groups were tested under 3 loading conditions, with 10 specimens per fixation per loading condition. Offset axial loading and externally ro
tated transverse loading was performed by mounting the tibial shaft in a multi-angle table vice and positioning it to simulate adduction and external rotation forces, respectively, as has been described previously.\(^\text{18,19}\)

The tension loading construct was created by placing a 4.2-mm drill hole in the medial malleolar fragment between the screws or K-wires and placing a 5/32-in metallic tension pin and finally a 3/32-in metal cable threaded through the tension pin as a way to create a tension load (Figure 4). The purpose of the tension pin was to distribute the load of the cable equally across the medial malleolar fragment to prevent cutout. Tibial specimens were cut transversely 15 cm proximal to the plafond, and a 6-mm K-wire was drilled through 2 walls of a custom holding block securing the tibial shaft (Figure 5). The metal cable was clamped in a circular fashion and placed over a transverse bar to provide the tensile load, simulating the force placed on the medial malleolar fragment through the deltoid ligament. Loading was performed on a servohydraulic test frame (Bionix 858; MTS Corp, Eden Prairie, Minnesota). Both tension-band wiring constructs, stainless steel (10 specimens) and FiberWire (10 specimens), were tested under the tension loading condition only, as described above.

All specimens were loaded under displacement control at a rate of 0.2 mm/second until catastrophic failure. All data were collected on a TestStar system (MTS Corp). Each specimen was only loaded once; none of the implants were reused during testing. The stiffness of each construct was calculated from the slope of the linear portion of the force versus displacement curve.

An a priori power analysis based on a 2-sample \(t\) test with a type 1 error of 5% (\(\alpha<.05\)), based on the means and standard deviations of previous studies, indicated that a sample size of 7 Sawbones per group had an 80% power of detecting the difference in failure loads. Two-sample \(t\) tests were used for analysis of constructs with significance set at \(\alpha<.05\). The bicortical construct was directly compared to...
the unicortical construct under all 3 loading conditions.

In a separate arm of the statistical analysis, the stainless steel tension-band group was compared to the FiberWire tension-band group. A 1-way balanced analysis of variance (ANOVA) was used to compare and identify significant differences among the 4 different constructs under tension load only. To specifically identify which pairs of means were significantly different, we used a 2 sample t tests with a Bonferroni correction and determined the significance level as α<.0125, as a conservative adjustment.

**RESULTS**

Due to difficulty with data acquisition, data were not obtained from 1 specimen in the bicortical group and 2 specimens in the unicortical axial loading group. Therefore, a total of 8 unicortical specimens were compared with 9 bicortical specimens under axial load; all other fixation groups under each loading condition consisted of 10 specimens.

No statistically significant differences were found in the axial loading condition. For transverse loading conditions, the bicortical construct was statistically stronger than unicortical fixation at 2 mm of fracture displacement (P<.001) and at catastrophic failure (P<.001) (Table 1). Stiffness, however, was not statistically significant for the transverse loading condition. Tension loading showed a statistically significant difference in strength at 2 mm of fracture displacement (P=.001), at catastrophic failure (P<.001), and in mean stiffness for the bicortical compared to the unicortical fixation group (347±137 vs 36±15 N/m, respectively, P<.001). Unicortical construct mean stiffness was only 10% the strength of the bicortical construct under tension loads.

The mechanism of catastrophic failure for the bicortical and unicortical groups, in both axial and transverse loading, was similar with screw displacement through the cancellous portion of the specimens until abutment of the screw against the cortex occurred. Interestingly, in the tension group, the unicortical construct failed by pullout (mean force=317 N) as expected, whereas the bicortical group demonstrated greater pullout strength (mean force=2015 N) that caused the cable to cutout of the medial malleolar fragment prior to failure at the fracture site.

In the tension-band wiring arm of the study, under tension loading, the stainless steel construct was significantly stiffer than the FiberWire construct (145±26 N vs 97±32 N/m, respectively, P=.007) (Table 2). At 2 mm of displacement, the FiberWire group was 80% the mean strength of the stainless steel group.

A 1-way ANOVA comparing across fixation construct groups in tension confirmed that differences in mean stiffness were significant (P<.001). The t test with the Bonferroni correction (α<.0125) revealed that the bicortical construct was a statistically stiffer construct than stainless steel (P=.001) and FiberWire (P<.001). Both the stainless steel and FiberWire fixation groups were stiffer than the unicortical group (P<.001 for both stainless steel and FiberWire). Mean stiffness and standard deviations are shown in Figure 6.

**Table 1**

<table>
<thead>
<tr>
<th>Loading Mechanism</th>
<th>Bicortical Screw Fixation</th>
<th>Unicortical Screw Fixation</th>
<th>P Value</th>
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</thead>
<tbody>
<tr>
<td>Axial</td>
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<tr>
<td>2 mm of displacement, N</td>
<td>328±78</td>
<td>374±156</td>
<td>.500</td>
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<tr>
<td>Catastrophic failure, N</td>
<td>498±147</td>
<td>535±182</td>
<td>.579</td>
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<tr>
<td>Stiffness, N/mm</td>
<td>126±53</td>
<td>139±67</td>
<td>.629</td>
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<tr>
<td>Transverse</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>2 mm of displacement, N</td>
<td>190±63</td>
<td>109±27</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Catastrophic failure, N</td>
<td>462±141</td>
<td>201±123</td>
<td>&lt;.001</td>
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<tr>
<td>Stiffness, N/mm</td>
<td>56±19</td>
<td>45±27</td>
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<tr>
<td>Tension</td>
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<td></td>
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<tr>
<td>2 mm of displacement, N</td>
<td>467±214</td>
<td>172±142</td>
<td>.001</td>
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<tr>
<td>Catastrophic failure, N</td>
<td>2015±540</td>
<td>317±60</td>
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<tr>
<td>Stiffness, N/mm</td>
<td>347±137</td>
<td>36±15</td>
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**Table 2**

<table>
<thead>
<tr>
<th>Load</th>
<th>Stainless Steel (18 gauge)</th>
<th>FiberWire (#5)</th>
<th>P Value</th>
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<tbody>
<tr>
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<td></td>
<td></td>
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<tr>
<td>2 mm of displacement, N</td>
<td>325±48</td>
<td>262±75</td>
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<td>Catastrophic failure, N</td>
<td>1138±70</td>
<td>579±177</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Stiffness, N/mm</td>
<td>145±26</td>
<td>96±32</td>
<td>&lt;.001</td>
</tr>
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</table>
DISCUSSION

Michelson et al\textsuperscript{21} reported the kinematic behavior of ankles following malleolar fracture repair under an axially loaded model with active motor unit firing. Compared with axially loaded passive motion studies, they found a greater amount of bony stability with loading of the ankle joint through stance phase. However, they expressed a greater concern for the stability of the ankle joint during the swing phase of gait, potentially causing a greater tension applied to the medial malleolus through the deltoid ligament. We are unaware of any studies or data that relate to the typical force in tension applied to a medial malleolar fracture during the swing phase of gait.

The most common treatment as recommended by the AO-ASIF group for medial malleolar fractures (OTA 44-B2.2 17) is partially threaded 4-mm cancellous screws at lengths of approximately 40 mm to ensure purchase in the dense cancellous bone in the metaphyseal region of the distal tibia. Biomechanical studies have shown that bicortical screws have up to 24\% stronger pullout strength, higher torque values, greater yield strength, and maximal load at failure in 3-point bending compared to unicortical screws.\textsuperscript{9,22,23}

There is little in the literature regarding fixation of the medial malleolus with bicortical screws. Kupcha and Pappas\textsuperscript{10} described a surgical technique of a bicortical medial malleolar screw that was angled from inferior to superior to purchase the second cortex on the medial side of the tibia, just above the malleolus. Recently, a cadaver biomechanical study of medial malleolar fractures compared the use of bicortical screws, similar to the technique used in our study, to traditional partially threaded cancellous screws in a tension-loaded model.\textsuperscript{11} They showed stronger pullout strength at 2 mm of fracture displacement in the bicortical screw construct, which supports our results that a bicortical screw construct is a stronger and stiffer construct in tension.

In addition, our study showed bicortical screws were a stronger construct in transverse loading at 2 mm of fracture displacement, as well as catastrophic failure. This stronger bicortical construct may protect the medial malleolus from the increase in tension forces applied through the deltoid ligament during the swing phase of gait, as well as counteracting rotational forces applied through the fracture in a weight-bearing noncompliant patient.

Tension-band wiring with 18-gauge stainless steel wire also has been advocated by many authors for use in osteoporotic bone or avulsion fractures that are too small to accept screw fixation.\textsuperscript{2,3,5,12,13} Multiple studies have shown the tension-band wiring and stainless steel technique to be a stronger construct than unicortical partially threaded screws in a cadaver model exposed to pronation loads.\textsuperscript{3,13} Our results support these studies that tension-band wiring technique with stainless steel or FiberWire is a stiffer construct than unicortical screws. However, the bicortical screw construct also proved to be stiffer than both tension-band wiring techniques (FiberWire and stainless steel). This challenges the idea that tension-band wiring for osteoporotic bone is the strongest and most appropriate construct. Our results suggest that in transverse or oblique fractures of the medial malleolus that are large enough to accept screws, it may be advantageous to use a bicortical screw technique. This should be interpreted with caution, as our Sawbones model is not representative of osteoporotic bone.

There still exists the clinical problem of avulsion fractures that are too small to accept screws. Tension-band wiring with stainless steel has proven to be an effective treatment for these types of fractures,\textsuperscript{2,4,12,13,24} however, soft-tissue irritation and prominent symptomatic implants continue to be a cause of patient dissatisfaction and often require secondary surgeries for implant removal.\textsuperscript{2,4,7,12,13,24} Ostrum and Litsky\textsuperscript{13} reported a 15\% complication rate related to painful prominent medial implants. In addition, Georgiadis and White\textsuperscript{7} reported 13.6\% of patients required removal of symptomatic implants.

We propose that substituting stainless steel wire with FiberWire in a tension-band wiring fixation construct of medial malleolar fractures could theoretically decrease soft-tissue irritation and secondary operations by decreasing the bulk of the implant.

The concept of replacing stainless steel wire with suture in a figure-of-eight fashion remains controversial in the literature, with the main criticism being that suture...
fixation cannot achieve rigid fixation.\textsuperscript{25} Carofino et al\textsuperscript{26} showed no difference in strength of a tension-band wiring and FiberWire suture compared to tension-band wiring and 18-gauge wire in a cadaver olecranon fracture model. Wright et al\textsuperscript{27} showed superior strength of FiberWire compared to 18-gauge stainless steel wire in a transverse patellar fracture model with 3-point bending. In addition, Cleak et al\textsuperscript{12} presented a technique that uses a medially placed 4.5-mm screw to anchor the figure-of-eight construct; this technique has been used by other authors.\textsuperscript{23,24} The technique allows for less soft tissue stripping than what is required for the intersosseous tunnel used for anchoring the proximal limb of the tension band compared to the standard technique and reduces the possibility of wire cutout through osteoporotic bone.

We used a similar technique with a 4-mm fully threaded cancellous screw to anchor the FiberWire. However, our results showed that FiberWire was not as strong as stainless steel, having only 80\% the strength of the stainless steel construct at 2 mm of fracture displacement ($P = .03$). It was also shown that the tension-band wiring and stainless steel construct was a significantly stiffer construct compared to the FiberWire ($P = .007$).

There are limitations to this study affecting the clinical relevance of our data. The question arises as to how much force the deltoid is exposed to clinically during times of high stress such as the swing phase of gait. All of the techniques tested in our study may be well above the clinical strength and stiffness needed to withstand physiological forces in compliant patients. There are no data in the literature to answer this question, which may be a focus of future studies. The concern arises when dealing with a non-compliant patient whose ankle is exposed to increased loads where this extra strength in construct may be beneficial.

Our testing model using 4th-generation composite Sawbones has advantages of improved strength, strain, and tensile properties compared to older generation models.\textsuperscript{14-16} We chose this model, as there is decreased variability between these Sawbones models and cadaveric bone, to achieve more consistent results. Despite this, neither Sawbones or cadaveric bone can replicate live bone exposed to physiological stresses as healing of the fracture commences. In addition, our model does not replicate osteoporotic bone, and our experimental model is limited in this regard.

**CONCLUSION**

We found a statistically significant difference in strength of bicortical versus unicortical screw fixation at 2 mm of fracture displacement and catastrophic failure for short oblique medial malleolar fractures in transverse and tension loading conditions. Bicortical screws also created a significantly stiffer construct in tension. Medial malleoli repaired with bicortical screws were also shown to be significantly stiffer than both tension-band constructs with stainless steel 18-gauge wire or FiberWire. For medial malleolar fractures that are large enough to accept screw fixation, a bicortical construct may prove to be a more mechanically sound technique. Prospective randomized studies are needed to clinically recommend using bicortical screws, for medial malleolar fractures, in which unicortical or tension-band technique would normally be used.

Our results showed inferior biomechanical properties of tension-band technique substituting FiberWire for 18-gauge stainless steel wire under tension loading. In the absence of data demonstrating the amount of physiological force placed across the deltoid after fracture of the medial malleolus and the absence of clinical randomized studies, we cannot support the use of FiberWire in a tension-band construct for medial malleolar fractures.

**REFERENCES**


